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C7A 745 746 78Y A23Y A241 A243 A245 A247 A249 A24X A255 A257 A259 A25Y A260 A28X A28Y A309 A30Y A311 A313 A316 A319 A31X A320 A323 A326 A329 A339 A33Y A340 A341 A343 A345 A347 A35Y A360 A362 A379 A37X A37Y A381 A383 A385 A387 A389 A38X A396 A398 A39Y A400 A402 A404 A406 A409 A40Y A41X A41Y A425 A428 A432 A435 A437 A439 A43X A449 A44Y A451 A453 A455 A457 A459 A45X A48Y A499 A501 A503 A505 A507 A509 A50X A517 A519 A51Y A521 A523 A525 A527 A529 A52X A53Y A541 A543 A545 A547 A559 A55Y A562 A565 A568 A56X A571 A574 A577 A579 A57Y A584 A587 A589 A58Y A591 A593 A595 A59X A601 A603 A605 A607 A609 A60Y A615 A617 A619 A61X A61Y A621 A623 A62X A671 A673 A675 A677 A679 A67X A681 A683 A685 A687 A689 A68X A693 A695 A696 A697 A698 A699 A69X A70X
U1S 1577 3045 C7A

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(58) Field of search
C7A

(54) Process for preparing a high strength stainless steel material having excellent workability and free from weld softening

(57) A stainless steel which exhibits substantially martensitic structure at room temperature is heated at a temperature of 550 to 675°C for 1 to 30 hours. A reverse-transformed austenite phase appears and a stainless steel having high strength and high elongation and being free from weld softening is obtained.

The composition of the steel lies within the range:

	%
C	0·10 max
Si	0·20 – 4·5
Mn	0·20 – 5·0
P	0·060 max
S	0·030 max
Cr	10·0 – 17·0
Ni	3·0 – 8·0
N	0·10 max
Fe and impurities	Bal

Up to 4% in total of Cu, Mo, W and Co may be present with up to 1% in total of Ti, Nb, V, Zr, Al and B. The relationship

$$Ni_{eq} = 13{\cdot}0 \text{ to } 17{\cdot}5 = Ni + Mn + 0{\cdot}5G + 0{\cdot}3Si + 20[C + N]$$

must also be satisfied.

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FIG. 1

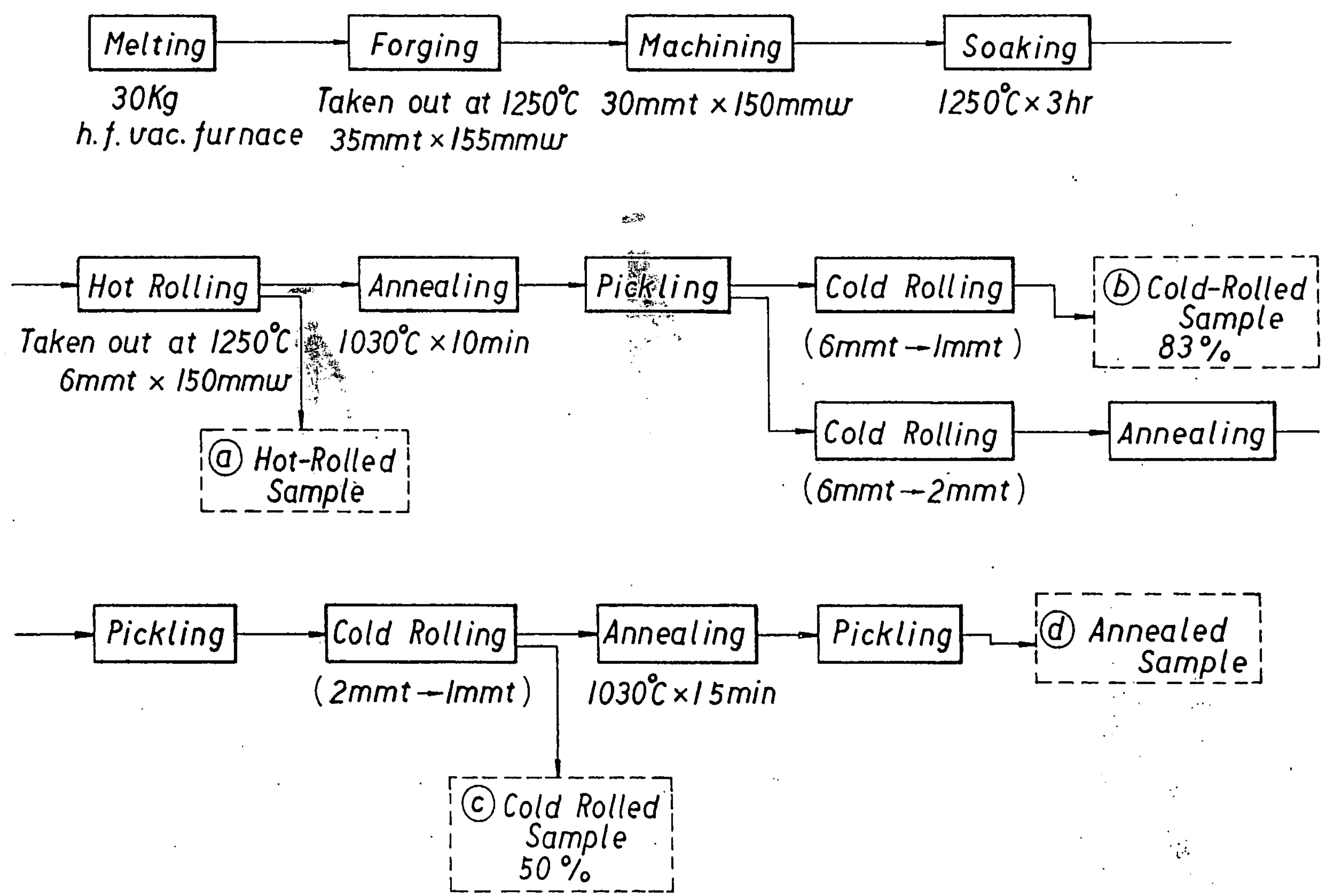
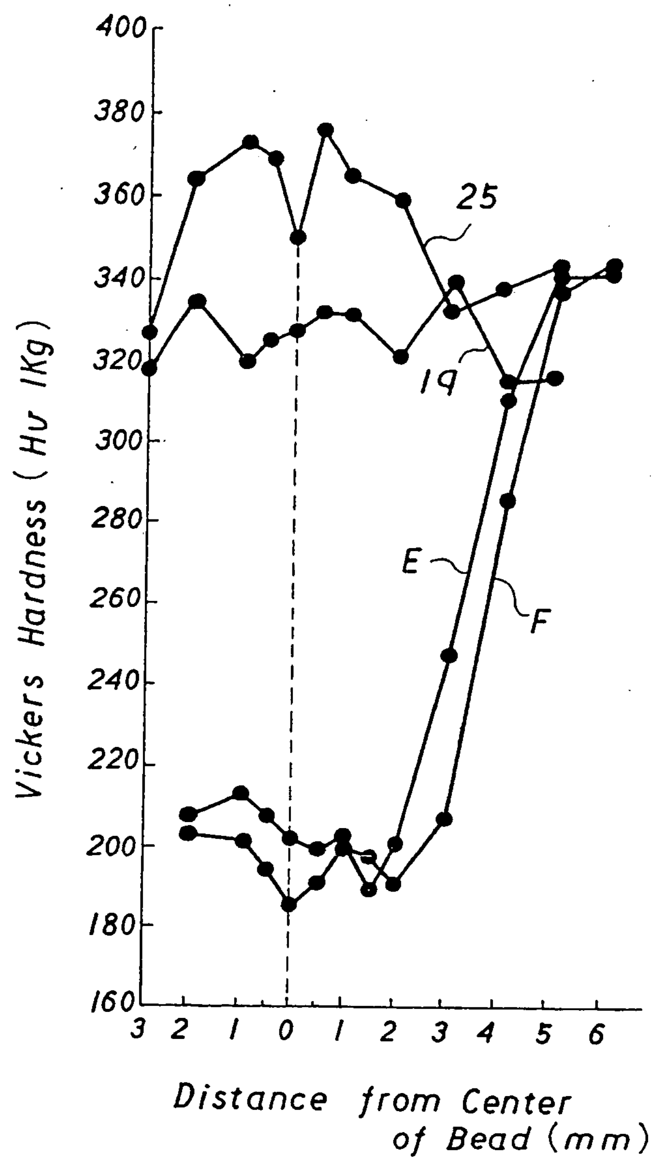


FIG. 2



400
380
360
340
320
300
280
260
240
220
200
180
160
Vickers Hardness (Hv 1Kg)
25
19
E
F
3 2 1 0 1 2 3 4 5 6
Distance from Center of Bead (mm)

SPECIFICATION

Title of the Invention

Process for preparing a high strength stainless steel material having excellent workability and free from weld softening

Field of the Invention

This invention relates to a high strength stainless steel material having excellent workability and resistance to softening by welding.

Background of the Invention

Conventional high strength stainless steels are roughly classified into (1) martensitic stainless steels, (2) work-hardenable austenitic stainless steels, and (3) precipitation-hardenable stainless steels.

Martensitic stainless steels mainly comprise Fe-Cr-C system and are substantially of single austenitic phase at the quenching temperature (which is 900–1100°C, but varies depending on the content of Cr and C), but their martensite start point (Ms point) is higher than the room temperature range and they are so-called quench-hardenable steels.

These steels are hard and poor in workability in the quenched state or the quenched and tempered state. Therefore, in these steels, working such as bending, machining and cutting is carried out in the annealed state and high strength is provided by a heat-treatment such as quenching and tempering after the steel is shaped as desired. However, heat-treatment of large parts or members is difficult, and these steel materials are susceptible to weld cracking, and, therefore, tempering must be carried out after welding.

When martensitic stainless steels are to be used as structural members, the above-mentioned defects must be compensated for. To this end, a steel in which the C content is restricted lower so that a massive martensite phase appears in the quenched state has been considered. The steel of Japanese Patent Publication No. 51-35447 (1976) is an example of such a steel. A steel which falls within the claim of said patent publication is presented in No. 33 of "Nisshin Seiko Giho (Technical Reports of Nisshin Steel Co.)" (December 1975 issue). The composition thereof is: C: 0.032 %, Si: 0.75%, Mn: 0.14%, Ni: 4.01%, Cr: 12.4%, and Ti: 0.31%. This material has a tensile strength of about 108 kgf/mm^2 and an elongation of about 6%, and that is very low in weld softening. Although low weld softening and high tensile strength are desirable for a welded structural material, the steel is still unsatisfactory as a structural material to be worked since elongation is poor and cracking easily occurs even in light working.

Work-hardenable austenitic stainless steels have the metastable austenitic phase as represented by AISI 301, 201, 304, 202, etc., and are hardened by cold working. Mechanical properties attained by this cold working are stipulated in JIS G 4307. For instance, in 1/2H of AISI 301, it is specified that yield strength is not less than 77 kgf/mm^2, tensile strength is not less than 105 kgf/mm^2 and elongation is not less than 10%. That is, both tensile strength and elongation are specified as being high. However, the materials of this class have a defect in that when they undergo heat input such as welding, the heated part or weld softens. Also in some cases, chromium carbide deposit in the part heated by welding, and chromium-poor layers are formed and thus intergranular stress corrosion cracking occurs.

Precipitation-hardenable stainless steels are classified into martensite type, ferrite type and austenite type in accordance with the structure of the matrix. But all of them contain at least one of A1, Ti, Nb, Cu, Mo, V, etc., which contribute to age-hardening, and the steels are hardened by precipitation of intermetallic compounds caused by aging from the super-saturated solid-solution state. These steels have a tensile strength of 140 – 190 kgf/mm^2 and an elongation of 2 – 5%, depending upon the state of the matrix, contents of the elements which contribute to age-hardening, etc.

When these steels are used for structural members, generally working and welding are effected prior to age-hardening. However, it is difficult to age-harden larger structural members.

As has been described, the materials conventionally known as high strength stainless steels do not possess all of strength, workability and resistance to weld softening.

The object of the present invention is to provide a novel high strength steel material free from the above-described defects. The object is achieved by heating a steel material of a martensitic structure, which is in a specific composition range and that satisfies a specific composition relationship, to cause reverse austenitic transformation and stabilize the thus formed reverse-transformed austenite phase.

Summary of the Invention

This invention provides process for preparing a high strength stainless steel material having excellent workability free from weld softening consisting of a single martensitic phase or a duplex phase structure of martensite and minute austenite, said process comprising heat-treating at a temperature of 550 to 675°C for 1 to 30 hours a hot-rolled, cold-rolled or annealed material of a steel essentially consisting of:

C: not more than 0.10%
Si: 0.20 – 4.5%
Mn: 0.20 – 5.0%
P: not more than 0.060%
S: not more than 0.030%

Cr: 10.0 – 17.0%
Ni: 3.0 – 8.0%
N: not more than 0.10%

and Fe and inevitable incidental impurities, wherein the Ni_{eq} value defined as:
$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + 20(C + N)$ is in the range of 13.0 – 17.5

This invention also provides processes for preparing similar steel materials using steels which contain in addition to the above-described components not more than 4% in total of at least one of Cu, Mo, W, and Co and/or not more than 1% in total of at least one of Ti, Nb, V, Zr, A1 and B, wherein the definition of Ni_{eq} is modified in accordance with the composition.

When at least one of Cu, Mo, W and Co is contained, the Ni_{eq} value is defined as:

$$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + 20(C + N) + Cu + Mo + W + 0.2Co$$

When at least one of Ti, Nb, V, Zr, Al and B is contained, the Ni_{eq} value is defined as :

$$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si$$

When at least one of Cu, Mo, W and Co and at least one of Ti, Nb, V, Zr, Al and B are contained, the Ni_{eq} value is defined as:

$$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + Cu + Mo + W + 0.2Co$$

The steel preferably contains 0.005 – 0.08% and more preferably 0.010 – 0.06% C; preferably 0.25 – 4.0% and more preferably 0.40 – 4.00% Si; preferably 0.30 – 4.50% and more preferably 0.40 – 4.0% Mn; preferably not more than 0.040% and more preferably not more than 0.035% P; preferably not more than 0.02% and more preferably not more than 0.015% S; preferably 11.0 – 16.0% and more preferably 12.0 – 15.0% Cr; preferably 3.5–7.5% and more preferably 4 – 7.5% Ni; preferably not more than 0.07% and more preferably not more than 0.05% N; preferably 0.5 – 3.5% and more preferably 1.0 – 3.0% of at least one of Cu, Mo, W and Co when contained; and preferably 0.1 – 0.8% and more preferably 0.15 – 0.8% of at least one of Ti, Nb, V, Zr, Al and B when contained.

The above-mentioned steel for the process of the present invention exhibits substantially martensitic structure in any of the hot-rolled state, cold-rolled state and annealed state, as a result of adjusting the composition so that the Ni_{eq} value as defined above is in the above-defined range.

This invention is based on the inventors' finding that the above-mentioned steel, as hot-rolled, as cold-rolled or as cold-rolled and annealed, undergoes reverse austenitic transformation and stabilized by heat-treating the steel at a temperature of 550 – 675°C for 1 – 30 hours. The mechanism involved and reason for it are not yet well understood, but it has been confirmed that this reverse austenitic transformation occurs with reproducibility. Modification of the properties of stainless steel of martensitic structure by such a treatment has never been attempted before.

The steel material of the present invention exhibits a strength level of about 100 kgf/mm^2 and an elongation of about 20%, and does not suffer from weld softening.

The reason why the composition of the steel is defined in the claim in the present invention is as follows:

C: C is an austenite former, and effective for formation of austenite phase at high temperatures, and is also effective for strengthening the reverse transformed austenite phase and martensite phase after the heat treatment. However, a larger amount of C impairs elongation, and deteriorates corrosion resistance of the weld. Therefore, it is limited to 0.10%.

N: Like C, N is an austenite former, effective for formation of the austenite phase at high temperatures, and also hardens the reverse transformed austenite phase, and is therefore, effective for strengthening the steel. However, a larger amount of N deteriorates elongation. Therefore, N is limited to 0.1%.

Si: Si is effective for strengthening the reverse transformed austenite after the heat treatment and is effective for broadening the allowable temperature range for heat treatment. For this purpose, at least 0.2% Si is required. However, a large amount of Si promotes solidification cracking when the steel is solidified or welded. Therefore, the upper limit of the Si content is defined as 4.5%.

Mn: Mn is an austenite former and necessary for adjustment of the Ms point. For this purpose, at least 0.2% Mn is required. But a larger amount of Mn causes troubles in the course of steelmaking and therefore its upper limit is defined as 5%.

Cr: Cr is a fundamental component for providing the steel with corrosion resistance. However, with less than 10%, no effect can be expected, while more than 17% of Cr requires a larger amount of austenite former elements in order to produce a single austenite phase at high temperatures. The upper limit of Cr is defined as 17% so that the desired structure is obtained when the steel is brought to room temperature.

Ni: Ni is an austenite former, and is necessary for obtaining a single austenite phase at high temperatures and adjustment of the Ms point. The Ni content depends on the contents of the other elements. At least about 3% of Ni is required for obtaining a single austenite phase at high temperatures and adjustment of the Ms point. Even if the contents of the other elements are reduced, more than 8% of Ni does not give the desired structure.

P: P is an inevitable impurity element incidental to principal and auxiliary raw materials. P makes steels brittle and therefore it is limited to 0.060% at the highest.

S: S is also an inevitable impurity element incidental to principal and auxiliary raw materials in steelmaking. S also makes steels brittle and therefore it is limited to 0.030% at the highest.

Cu: Cu is inherently effective for improving corrosion resistance. In the present invention Cu is effective for lowering the Ms point. However, if it is contained in an amount in excess of about 4%, workability at high

temperature is impaired. Therefore, its content is limited to 4%.

Mo: Mo improves corrosion resistance and is effective for strengthening the reverse transformed austenite and lowering the Ms point. However, Mo is an expensive element and its content is limited to 4% in consideration of the cost of the steel.

W: W is effective for improving corrosion resistance and strength of the steel, and is also effective for lowering the Ms point. However, the upper limit is defined as 4%, since it raises the cost of the steel if it is contained in a larger amount.

Co: Co has a high austenitizing effect at the high temperature range, and lowers the Ms point. (Although this element has high austenitizing effect, it does not lower the Ms point excessively.) Co is very effective for adjustment of composition in a high Cr content system. But the upper limit on the content thereof is defined as 4%, since it raises the cost of the steel if it is contained in a larger amount.

The last four elements mentioned above improve corrosion resistance and are effective for adjusting the martensite-forming ability of the steel in relation with the other components. They are equivalent in this sense.

Ti: Ti is a carbide-former and effective for preventing formation of Cr-poor layers caused by deposition of the carbide in welding and inhibition of grain growth of the reverse transformed austenite phase. However, if this is contained in a large amount, it may cause surface defects and may form a larger amount of scum in welding. Therefore, the Ti content is limited to 1%.

Nb: Nb is effective for preventing formation of Cr-poor layers caused by precipitation of Cr carbide in welding and inhibition of grain growth of the reverse transformed austenite phase. If it is contained in a larger amount, however, it promotes solidification cracking when cast or welded, and also impairs ductility of the steel material. Therefore its content is limited to 1%.

V: V is effective for preventing formation of Cr-poor layers and inhibition of grain growth of the reverse transformed austenite. If it is contained in a larger amount, however, it impairs ductility of the steel. Therefore, its content is limited to 1%.

Zr: Zr is effective for preventing formation of Cr-poor layers caused by deposition of carbide in welding and inhibition of grain growth of the reverse transformed austenite phase. If it is contained in a larger amount, however, oxide type non-metallic inclusions are formed in casting and welding, and the surface properties and ductility of the steel are impaired. Therefore, its content is limited to 1%.

Al: Al has a remarkable effect for fixing N in the molten steel and inhibiting grain growth of the reverse transformed austenite phase. If it is contained in a larger amount, it impairs flow of the molten metal in welding and thus makes the welding operation difficult. Therefore, the Al content is limited to 1%.

B: B is effective for inhibition of grain growth of the reverse transformed austenite and improvement of hot workability of the steel. If it is contained in a larger amount, however, it impairs ductility of the steel. Therefore, its content is limited to 1%.

The last six elements mentioned above are carbide formers, and remarkably effective in inhibiting grain growth of the reverse transformed austenite. In this sense, these six elements are equivalent.

The reason for defining the nickel equivalent (Ni_{eq}) as defined in the claims is as follows. In the steel used for the present invention, the temperature at which the martensite transformation is finished must be around room temperature (150 – −10°C). The steel used in the process of the present invention is of single austenite phase in the temperature range to which the steel is exposed during hot rolling, annealing or welding. But the steel must be substantially transformed into the martensite structure when the steel is brought down to room temperature from the above-mentioned condition. Here the term "substantially" means that a small amount (approximately 25%) of austenite may be retained. The amount of such remaining austenite need not be strictly considered.

In the steel used in the present invention, various elements are alloyed. We have found that insofar as the composition of the steel falls within the above-described composition range and that the nickel equivalent (Ni_{eq}) thereof as defined above is in the above-described range, the steel is of substantially martensite structure at room temperature and the object of the invention as described in the beginning of this specification is achieved.

That is to say, even though the composition is within the above-defined range, if the nickel equivalent is less than 13, the Ms point is too high and the desired high elongation cannot be obtained even if the steel is heat-treated as defined above. If the nickel equivalent is greater than 17.5, the steel softens at the weld when it is welded, and thus the desired high strength members cannot be obtained. Needless to say, the formula for Ni_{eq} was defined by considering the degree of contribution of each element to the austenite-martensite transformation and thus determining each coefficient as the equivalent of the Ni amount in comparison with the degree of the contribution of Ni. Ti and the five elements that follow are neutral with respect to the above-described property, and that cancel the austenite-forming ability of C and N. Therefore, in the steels which contain these elements, these elements and C and N are not taken into consideration.

The reason for defining the heat treatment conditions as defined in the present invention is as follows:

The steels which are of the martensite structure (massive martensite) in the annealed state have around 100 kgf/mm^2 of tensile strength. But as their elongation is about 6% at the utmost, it cannot be said that they have satisfactory workability. When the steels are kept at a temperature in a range of 550 – 675°C for 1 – 30 hours so that part of martensite is reverse-transformed to austenite, the thus formed austenite is more or less stable as a structure, not all thereof returns to martensite in the cooling that follows, and may remain as austenite. At any rate, this heat-treatment confer high ductility to the steel without remarkably lowering strength (yield strength). At temperatures lower than 550°C, the heat treatment does not effectively bring about this ductility, and at temperatures higher than 675°C, yield strength as well as ductility are impaired.

The time of the heat treatment is suitably selected by taking the size of the material to be treated into consideration. A heat treatment over 30 hours is disadvantageous since it raises the cost of the steel.

The steel material of the present invention is suitable for manufacturing structural parts and members as well as steel belt. The steel material possesses high strength, high ductility and does not suffer weld softening.

Now the invention will be explained specifically by way of working examples with reference to the attached drawings.

Brief Explanation of the Attached Drawings

Figure 1 is a flow chart illustrating preparation of samples in the present invention, and *Figure 2* is a diagram showing the softening at the weld in samples of the present invention and comparative examples.

Description of Specific Embodiments of the Invention

Sample steel heats were prepared using a vacuum high frequency furnace of 30 kg capacity by the usual process, and cast into ingots 110 × 110 mm at the bottom plane, 120 × 120 mm at the top plane and 290 mm in height. The ingots were forged into plates 35 mm in thickness and 155 mm in width at 1250°C, and the plates were machined into plates measuring 30 mm × 150 mm. The plates were heated at 1250°C in a soaking pit and thereafter hot-rolled to 6 mm of thickness. A portion thereof was tested as hot-rolled samples (a), and the other portion was annealed at 1030°C for 10 minutes, pickled and cold-rolled into sheet of 1 mm thickness (83% reduction), a portion thereof was tested as cold-rolled sample (b). The remaining portion was cold rolled to 2 mm thick sheets and further cold-rolled after intermediate annealing to 1 mm thick sheets (50% reduction) and a portion thereof was tested as 50% reduction cold-rolled sheet samples (c). The remaining portion was further annealed at 1030°C for 1.5 minutes and pickled. These were tested as annealed samples (d). Procedures of preparing samples are illustrated in Figure 1.

The compositions of the samples of this invention and the comparative samples are indicated in Table 1. Sample Nos. 1 – 32 are steels used in the process of this invention and Nos. A – F are steels of comparative examples. The compositions of these samples are within the defined composition range, but the nickel equivalent Ni_{eq} of Samples A – D are less than 13 and those of Samples E – F is greater than 17.5.

Mechanical property tests were carried out using test pieces No. 5 and No. 13B stipulated in JIS Z 2201.

The amount of martensite was measured using a vibrating sample magnetometer.

Mechanical properties and the amount of martensite of the samples are summarized in Table 2. In Table 2, "Conventional Process" means that the heat treatment in accordance with this invention was not carried out.

According to Table 2, the steels which were not heat-treated in accordance with the present invention and exhibit a substantially massive martensite structure in the annealed state have high level strength such as yield strengths of 73 – 126 kgf/mm^2 and tensile strengths of 94 – 135 kgf/mm^2, but their elongation is at the utmost 7.0%. This is remarkably low in comparison with Sample E and F, which are 20% cold-rolled sheets. Even among the samples which underwent the heat treatment of the present invention, those of the comparative steels have only 8.5% elongation at the highest, though even this is some improvement. The samples of the present invention exhibit generally remarkable improvement in elongation while retaining yield strength, although some samples suffer slight decrease in yield strength.

The mechanical properties and the amounts of martensite when annealed samples (d) were heat-treated under various conditions are shown in Table 3. "Comparative Process" in Table 3 means examples in which samples were heat-treated at temperatures in excess of the heat treatment temperature range of the present invention. From Table 3, it is learned that there is a criticality around the upper limit heat treatment temperature of 675°C.

The welding test was carried out by laying a bead on 1 mm thick plates by TIG welding with 50 A electric current at a rate of 400 mm/min. The results are shown in Figure 2. Figure 2 shows hardness distribution profile from the center of beads. Sample 19 and 25, which are samples of the present invention, were heat-treated at 600°C for 20 hours. Comparative Sample E and F are 20% cold-rolled sheets. As seen in this figure, the samples of the present invention obviously do not exhibit softening at the weld.

TABLE 1

Chemical Composition and Ni_{eq} of the Steels for the Invention Process and Comparative Steels

	Sample No.	Composition (wt%) C	Si	Mn	P	S	Cr	Ni	N	Cu, Mo, Co, W	Ti, Nb, Al, Zr, B, V	Ni_{eq}
Steels for the Invention Process	1	0.060	0.25	1.58	0.027	0.009	12.96	3.52	0.012			13.1
	2	0.010	0.27	1.14	0.031	0.010	13.04	4.00	0.076			13.5
	3	0.013	0.22	0.36	0.029	0.007	12.77	7.43	0.019			14.9
	4	0.045	2.07	0.37	0.034	0.014	13.03	6.25	0.012			14.9
	5	0.021	0.54	0.47	0.021	0.009	16.99	5.01	0.015	Co: 3.01		15.2
	6	0.011	0.24	0.31	0.029	0.012	15.09	6.03	0.010	Cu: 2.12		16.5
	7	0.007	0.28	0.27	0.019	0.007	12.91	7.47	0.011	W: 1.84		16.5
	8	0.006	0.22	0.30	0.024	0.005	12.37	6.69	0.013	Mo: 2.60		16.2
	9	0.019	0.41	0.33	0.027	0.004	13.82	7.12	0.014	Cu: 0.76, W: 1.08		17.0
	10	0.013	0.26	3.80	0.020	0.006	12.87	3.03	0.019		Ti: 0.27	13.3
	11	0.014	0.28	4.69	0.035	0.013	12.90	3.02	0.018		Ti: 0.16	14.2
	12	0.030	0.25	2.87	0.022	0.009	12.99	4.98	0.015		Ti: 0.08	14.4
	13	0.014	0.92	0.38	0.026	0.007	13.04	7.38	0.015		Ti: 0.15	14.6
	14	0.011	2.02	0.37	0.030	0.012	13.04	7.31	0.014		Ti: 0.28	14.8
	15	0.034	2.15	0.31	0.027	0.008	12.92	6.67	0.020		Nb: 0.41	14.1
	16	0.026	0.85	0.30	0.031	0.010	15.62	6.94	0.013		Nb: 0.50	15.3
	17	0.014	0.37	0.29	0.036	0.014	14.21	7.02	0.015		Ti: 0.67	14.5
	18	0.020	0.54	0.39	0.029	0.006	14.08	6.60	0.027		Al: 0.77	14.2
	19	0.015	0.32	0.46	0.025	0.004	13.87	7.00	0.016		B: 0.39	14.5
	20	0.010	0.35	0.40	0.037	0.006	13.64	7.03	0.014		V: 0.47	14.4
	21	0.011	0.30	0.35	0.026	0.011	13.72	6.89	0.010		Zr: 0.59	14.1
	22	0.030	0.41	0.40	0.034	0.008	13.61	6.91	0.010		Ti: 0.50, Nb: 0.42	14.2
	23	0.028	0.35	0.42	0.028	0.006	13.57	7.04	0.010		Ti: 0.32, Al: 0.50	14.4
	24	0.056	1.90	0.39	0.021	0.005	13.06	6.25	0.013		Ti: 0.10, V: 0.25	13.8
	25	0.040	1.44	0.29	0.018	0.006	14.61	7.36	0.010	Cu: 1.01	Ti: 0.49	16.4
	26	0.038	1.52	0.21	0.027	0.011	13.87	7.02	0.008	Cu: 0.68, Mo: 1.02	Ti: 0.37	16.3
	27	0.007	3.05	0.31	0.024	0.008	13.16	6.33	0.015	Mo: 1.17	Ti: 0.10, Nb: 0.41	15.3
	28	0.007	2.04	0.30	0.032	0.012	12.18	5.40	0.011	Cu: 2.03	Nb: 0.45	14.4
	29	0.013	0.37	0.26	0.028	0.008	13.09	7.00	0.010	W: 0.82	Ti: 0.58	14.7
	30	0.010	2.56	0.24	0.028	0.005	14.56	6.37	0.009	Co: 2.31	Al: 0.70	15.1
	31	0.040	1.39	0.27	0.037	0.009	12.82	6.12	0.014	Cu: 0.91, W: 1.97	Ti: 0.81	16.1
	32	0.026	4.12	0.30	0.023	0.008	13.12	7.12	0.014			16.0
Comparative Steels	A	0.035	0.21	0.16	0.021	0.004	11.79	4.42	0.009		Ti: 0.27	10.5
	B	0.046	0.31	0.21	0.018	0.006	11.52	5.01	0.013		Nb: 0.40	11.1
	C	0.009	0.45	0.40	0.021	0.004	11.72	5.26	0.011			12.1
	D	0.014	0.28	1.32	0.019	0.007	10.86	3.97	0.025			11.6
	E	0.013	0.57	1.49	0.028	0.007	17.53	7.40	0.094			20.0
	F	0.058	0.51	1.14	0.025	0.005	17.44	7.10	0.070			19.7

TABLE 2

Mechanical properties and amount of martensite of products of the invention process and comparative products

	Sample No.	Conventional Process					Invention Process									
		As Annealed (d)					600°C × 10 hr. (As Annealed (d))					600°C × 10 hr. ((a))				
		$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)	$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)	$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)
Products of the Invention Process	1	126	135	4.3	394	100	98	110	13.6	332	97	101	116	15.2	337	96
	2	114	121	4.7	362	100	91	107	13.7	318	92	90	107	14.8	319	92
	3	77	100	5.9	328	100	71	84	17.4	271	87	73	87	16.8	280	88
	4	88	129	7.0	331	100	74	93	18.7	294	85	76	90	17.9	301	86
	5	76	99	5.7	304	97	72	94	16.2	300	86	72	90	16.5	297	85
	6	75	96	5.2	297	93	69	89	18.4	288	79	70	91	18.6	291	76
	7	81	97	5.2	300	94	74	97	17.7	305	72	74	95	17.1	298	71
	8	80	94	6.1	307	98	77	89	18.2	291	80	75	91	18.3	293	79
	9	82	96	5.8	297	90	79	91	17.9	298	73	78	92	18.1	296	75
	10	77	96	4.0	303	100	77	83	16.1	273	95	75	83	16.4	275	94
	11	75	98	5.8	293	95	75	80	16.7	303	80	74	81	17.1	272	81
	12	73	94	6.2	306	94	70	91	18.4	275	73	70	93	18.7	289	75
	13	74	106	6.4	322	99	71	91	18.9	272	81	73	94	18.2	287	79
	14	75	103	6.4	315	98	71	90	19.7	289	84	73	89	19.0	286	82
	15	91	118	5.7	336	94	76	92	18.2	301	79	78	93	18.5	293	79
	16	83	105	6.2	319	92	75	94	17.6	304	72	75	96	17.9	300	72
	17	86	108	4.2	322	100	79	98	17.4	312	93	78	98	18.1	315	91
	18	89	109	5.1	327	100	82	97	18.2	317	85	83	99	18.7	304	85
	19	92	116	4.7	334	96	80	102	16.8	321	82	81	99	16.8	319	82
	20	91	114	4.2	329	100	78	99	17.3	306	91	78	95	17.6	304	92
	21	98	111	4.0	317	100	85	109	18.6	330	94	86	101	19.2	326	93
	22	79	98	5.6	299	100	74	89	19.3	276	96	75	88	19.0	281	95
	23	84	103	6.1	309	100	72	91	18.5	284	95	70	85	18.2	276	93
	24	96	129	6.2	336	91	74	93	18.1	306	74	74	91	18.7	283	78
	25	93	115	3.9	327	91	85	124	16.1	323	70	85	119	16.2	311	73
	26	95	119	4.2	333	93	82	119	17.9	320	71	81	108	17.4	306	70
	27	95	121	5.0	327	97	84	116	16.8	319	79	83	112	17.0	311	78
	28	98	126	4.7	337	100	87	112	17.5	325	96	86	115	18.0	323	91
	29	83	110	5.1	316	100	78	95	18.1	307	94	80	95	17.7	311	93
	30	94	120	5.7	329	98	83	107	17.3	312	85	82	105	17.9	320	83
	31	87	114	6.2	324	94	80	97	18.4	305	81	76	93	19.0	298	74
	32	89	132	3.9	395	91	105	114	16.3	369	90	98	113	16.7	358	92
Comparative Products	A	94	105	6.0	330	100	82	97	7.3	302	100	82	95	6.8	297	100
	B	96	103	5.7	326	100	85	95	7.4	304	100	83	96	7.0	300	100
	C	89	97	5.5	307	100	82	94	7.0	296	100	81	94	6.7	294	100
	D	95	105	5.9	320	100	83	95	7.2	297	100	85	98	5.9	307	100
	E*	72	96	28.0	340	18										
	F*	70	109	26.3	342	21										

TABLE 2—*continued*

	Sample No.	600°C × 10 hr. ((b)) (83% Cold)					600°C × 10 hr. ((c)) (50% Cold)				
		Invention Process									
		$\sigma_{0.2}$ (kg/mm^2)	σ_B (kg/mm^2)	El (%)	Hv	mar. (%)	$\sigma_{0.2}$ (kg/mm^2)	σ_B (kg/mm^2)	El (%)	Hv	mar. (%)
Steels for the Invention Process	1	—	—	—	—	—	107	112	14.6	330	95
	2	99	110	16.2	324	90	98	107	15.3	320	92
	3	85	91	18.2	289	82	83	90	17.9	281	84
	4	89	102	19.3	317	81	87	98	18.9	314	84
	5	84	97	17.8	301	73	83	95	16.8	293	79
	6	83	95	19.1	289	70	81	92	18.9	289	72
	7	88	96	18.2	294	67	85	93	17.9	291	70
	8	89	95	20.4	307	73	86	91	19.1	302	71
	9	91	95	21.7	302	70	90	93	20.8	300	72
	10	81	89	20.3	294	91	81	85	19.6	281	93
	11	80	84	23.1	279	76	80	87	22.1	281	79
	12	76	82	20.6	275	68	76	81	19.8	286	67
	13	79	84	21.2	290	70	77	82	21.0	285	71
	14	91	92	20.7	291	75	86	93	20.5	289	78
	15	91	93	20.2	288	76	91	95	20.8	300	82
	16	80	84	19.4	279	65	80	86	19.0	284	69
	17	82	85	19.3	281	83	81	87	19.1	289	84
	18	88	91	21.3	294	80	89	94	21.5	299	80
	19	89	94	23.4	297	67	86	93	22.7	300	69
	20	86	91	20.1	292	84	82	90	19.8	288	84
	21	88	93	21.8	298	85	86	92	21.2	295	85
	22	83	87	20.9	281	87	81	86	20.0	291	86
	23	85	90	21.4	289	81	83	89	20.8	295	80
	24	80	83	20.2	275	68	81	85	20.5	287	67
	25	89	93	19.3	291	64	86	90	19.1	287	65
	26	86	91	20.0	287	63	85	91	20.8	293	66
	27	85	94	19.4	295	68	84	92	19.0	290	70
	28	89	93	21.4	306	74	89	96	20.9	310	73
	29	85	88	19.1	297	73	84	95	19.0	305	70
	30	86	93	19.7	301	68	85	91	19.3	295	69
	31	80	84	20.5	279	60	83	90	20.0	276	64
	32	114	117	16.8	384	85	105	110	16.5	369	88
Comparative Steels	A	85	99	8.3	298	100	84	103	8.0	315	100
	B	89	94	8.1	305	100	89	97	8.4	302	100
	C	83	97	8.5	300	100	85	98	8.0	299	100
	D	87	99	7.3	318	100	89	104	7.3	320	100
	E*										
	F*										

* E, F: 20% cold-rolled

TABLE 3

Mechanical properties and amount of martensite of the products of the invention process and the products of the comparative process (annealed materials)

Invention Process

Sample No.	550°C × 30 hr.					575°C × 5 hr.					600°C × 20 hr.				
	$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)	$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)	$\sigma_{0.2}$ (kg/mm²)	σ_B (kg/mm²)	El (%)	Hv	mar. (%)
3	74	85	15.7	286	98	77	86	15.3	290	96	71	84	17.3	276	85
4	80	87	16.1	291	98	95	106	15.4	311	97	75	89	18.4	291	82
6	75	83	15.4	290	94	82	91	14.9	300	90	68	90	18.5	293	75
9	82	97	16.4	313	97	89	101	15.5	322	90	75	87	18.0	284	72
12	75	84	15.8	287	97	75	83	14.9	283	97	70	90	18.9	285	73
13	80	85	16.8	291	98	83	88	15.3	298	96	72	93	18.7	281	75
14	89	95	16.1	322	98	100	105	15.1	340	96	73	88	19.3	283	80
18	91	99	16.0	320	96	104	110	15.0	337	93	82	95	19.1	300	84
25	84	111	16.3	334	96	89	110	15.6	330	90	86	117	17.4	328	71
28	85	110	15.7	326	98	91	106	14.8	325	95	82	108	18.5	321	89
31	87	98	16.9	300	98	82	101	15.4	316	97	78	96	19.4	303	72
32	97	119	13.3	356	100	98	117	15.3	358	95	100	113	17.3	353	92

TABLE 3—*continued*

Mechanical properties and amount of martensite of the products of the invention process and the products of the comparative process (annealed materials)

Sample No.	Invention Process 625°C × 1 hr. $\sigma_{0.2}$ (kg/mm^2)	σ_B (kg/mm^2)	El (%)	Hv	mar. (%)	Invention Process 675°C × 1 hr. $\sigma_{0.2}$ (kg/mm^2)	σ_B (kg/mm^2)	El (%)	Hv	mar. (%)	Comparative Process 710°C × 1 hr. $\sigma_{0.2}$ (kg/mm^2)	σ_B (kg/mm^2)	El (%)	Hv	mar. (%)
3	67	93	16.2	304	80	64	91	14.9	298	83	52	88	11.0	281	78
4	67	97	16.7	319	76	65	93	16.3	305	82	54	98	10.7	287	79
6	65	87	17.1	285	70	63	89	16.9	292	73	50	85	11.6	261	66
9	74	88	16.9	290	69	71	89	16.4	289	70	59	87	10.9	272	64
12	68	85	18.0	288	68	64	91	17.5	290	70	50	81	12.1	250	62
13	72	90	18.9	283	71	73	92	16.3	281	71	56	87	11.3	269	70
14	74	85	19.6	279	73	71	93	16.9	283	69	60	85	12.5	278	71
18	79	94	19.8	306	80	68	94	16.4	295	75	61	91	10.8	290	76
25	83	114	18.1	319	67	79	109	15.9	309	72	61	110	11.7	286	65
28	82	105	18.5	318	88	81	103	15.7	308	71	58	99	10.8	276	83
31	74	90	20.5	294	66	75	93	17.0	289	69	57	85	12.6	271	62
32	101	116	20.2	363	91	75	115	14.0	321	78	68	117	9.2	310	70

CLAIMS

1. Process for preparing a high strength stainless steel material having excellent workability free from weld softening consisting of a single martensitic phase or a duplex phase structure of martensite and minute austenite, said process comprising heat-treating at a temperature of 550 to 675°C for 1 to 30 hours a hot-rolled, cold-rolled or annealed material of a steel essentially consisting of:

C: not more than 0.10%
Si: 0.20 – 4.5%
Mn: 0.20 – 5.0%
P: not more than 0.060%
S: not more than 0.030%
Cr: 10.0 – 17.0%
Ni: 3.0 – 8.0%
N: not more than 0.10%

and Fe and inevitable incidental impurities, wherein the Ni_{eq} Value defined as: $Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + 20(C + N)$ is in the range of 13.0 – 17.5.

2. The process for preparing a high strength steel material as set forth in Claim 1, wherein the steel essentially consists of:

C: 0.005 – 0.08%
Si: 0.25 – 4.0%
Mn: 0.30 – 4.5%
P: not more than 0.04%
S: not more than 0.02%
Cr: 11.0 – 16.0%
Ni: 3.5 – 7.5%
N: not more than 0.07%

and Fe and inevitable incidental impurities.

3. The process for preparing a high strength steel material as set forth in Claim 2, wherein the steel essentially consists of:

C: 0.007 – 0.06%
Si: 0.40 – 4.0%
Mn: 0.40 – 4.0%
P: not more than 0.035%
S: not more than 0.015%
Cr: 12.0 – 15.0%
Ni: 4.0 – 7.5%
N: not more than 0.05%

and Fe and inevitable incidental impurities.

4. Process for preparing a high strength stainless steel material having excellent workability and free from weld softening consisting of a single martensitic phase or a duplex phase structure of martensite and minute austenite, said process comprising heat-treating at a temperature of 550 to 675°C for 1 to 30 hours a hot-rolled, cold-rolled or annealed material of a steel essentially consisting of:

C: not more than 0.10%
Si: 0.2 – 4.5%
Mn: 0.2 – 5.0%
P: not more than 0.060%
S: not more than 0.030%
Cr: 10.0 – 17.0%
Ni: 3.0 – 8.0%
N: not more than 0.10%

At least one of Cu, Mo, W and Co: not more than 4% in total and Fe and inevitable incidental impurities, wherein the Ni_{eq} value defined as:

$$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + 20(C + N) + Cu + Mo + W + 0.2Co$$

is in the range of 13.0 – 17.5.

5. The process for preparing a high strength stainless steel material as set forth in Claim 4, wherein the steel essentially consists of:

C: 0.005 – 0.08%
Si: 0.25 – 4.0%
Mn: 0.30 – 4.5%
P: not more than 0.04%
S: not more than 0.020%
Cr: 11.0 – 16.0%
Ni: 3.5 – 7.5%
N: not more than 0.07%

At least one of Cu, Mo, W and Co: 0.5 – 3.5% in total
and Fe and inevitable incidental impurities.

6. The process for preparing a high strength stainless steel material as set forth in Claim 5, wherein the steel essentially consists of:
C: 0.007 – 0.06%
Si: 0.40 – 4.0%
Mn: 0.40 – 4.0%
P: not more than 0.035%
S: not more than 0.015%
Cr: 12.0 – 15.0%
Ni: 4.0 – 7.5%
N: not more than 0.05%
At least one of Cu, Mo, W and Co: 1.0 – 3.0% in total
and Fe and inevitable incidental impurities.

7. Process for preparing a high strength stainless steel material having excellent workability and free from weld softening consisting of a single martensitic phase or a duplex phase structure of martensite and minute austenite, said process comprising heat-treating at a temperature of 550 to 675°C for 1 to 30 hours a hot-rolled, cold-rolled or annealed material of a steel essentially consisting of:
C: not more than 0.10%
Si: 0.2 – 4.5%
Mn: 0.2 – 5.0%
P: not more than 0.060%
S: not more than 0.030%
Cr: 10.0 – 17.0%
Ni: 3.0 – 8.0%
N: not more than 0.10%
At least one of Ti, Nb, V, Zr, Al and B: not more than 1% in total and Fe and inevitable incidental impurities, wherein the Ni_{eq} value defined as:
$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si$ is in the range of 13.0 – 17.5.

8. The process for preparing a high strength stainless steel material as set forth in Claim 7, wherein the steel essentially consists of:
C: 0.005 – 0.08%
Si: 0.25 – 4.0%
Mn: 0.30 – 4.5%
P: not more than 0.04%
S: not more than 0.02%
Cr: 11.0 – 16.0%
Ni: 3.5 – 7.5%
N: not more than 0.07%
At least one of Ti, Nb, V, Zr, Al and B: 0.1 – 0.8% in total and Fe and inevitable incidental impurities.

9. The process for preparing a high strength stainless steel material as set forth in Claim 8, wherein the steel essentially consists of:
C: 0.007 – 0.06%
Si: 0.40 – 4.0%
Mn: 0.40 – 4.0%
P: not more than 0.035%
S: not more than 0.015%
Cr: 12.0 – 15.0%
Ni: 4.0 – 7.5%
N: not more than 0.05%
At least one of Ti, Nb, V, Zr, Al and B: 0.15 – 0.8% in total and Fe and inevitable incidental impurities.

10. Process for preparing a high strength stainless steel material having excellent workability and free from weld softening consisting of a single martensitic phase or a duplex phase structure of martensite and minute austenite, said process comprising heat-treating at a temperature of 550 to 675°C for 1 to 30 hours a hot-rolled, cold-rolled or annealed material of a steel essentially consists of:
C: not more than 0.10%
Si: 0.20 – 4.5%
Mn: 0.20 – 5.0%
P: not more than 0.060%
S: not more than 0.030%
Cr: 10.0 – 17.0%
Ni: 3.0 – 8.0%
N: not more than 0.10%
At least one of Cu, Mo, W and Co: not more than 4% in total
At least one of Ti, Nb, V, Zr, Al and B; not more than 1% in total and Fe and inevitable incidental impurities,

wherein the Ni_{eq} value defined as:

$Ni_{eq} = Ni + Mn + 0.5Cr + 0.3Si + Cu + Mo + W + 0.2Co$ is in the range of 13.0 – 17.5.

11. The process for preparing a high strength stainless steel material as set forth in Claim 10, wherein the steel essentially consists of:

C: 0.005 – 0.08%
Si: 0.25 – 4.0%
Mn: 0.30 – 4.5%
P: not more than 0.040%
S: not more than 0.020%
Cr: 11.0 – 16.0%
Ni: 3.5 – 7.5%
N: not more than 0.07%
At least one of Cu, Mo, W and Co: 0.5 – 3.5% in total
At least one of Ti, Nb, V, Zr, Al and B: 0.1 – 0.8% in total and Fe and inevitable incidental impurities.

12. The process for preparing a high strength stainless steel material as set forth in Claim 11, wherein the steel essentially consists of:

C: 0.007 – 0.06%
Si: 0.40 – 4.0%
Mn: 0.40 – 4.0%
P: not more than 0.035%
S: not more than 0.015%
Cr: 12.0 – 15.0%
Ni: 4.0 – 7.5%
N: not more than 0.05%
At least one of Cu, Mo, W and Co: 1.0 – 3.0% in total
At least one of Ti, Nb, V, Zr, Al and B: 0.15 – 0.8% in total and Fe and inevitable incidental impurities.

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